Soil-Borne Wheat Mosaic

By Benjamin Koehler, W. M. Bever, and O. T. Bonnett

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COVER PICTURE

The three wheat plants shown on the front cover include from left to right a mosaic-resistant plant, one moderately resistant, and one affected by the rosette type of mosaic damage.

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SOIL-BORNE WHEAT MOSAIC

By Benjamin Koehler, W. M. Bever, and O. T. Bonnett[a]

WHEAT MOSAIC is one of the few diseases of Illinois farm crops that under some conditions has caused almost complete crop failure. If resistant varieties had not been found, wheat would rarely be grown in parts of the state where it is now an important crop. Soil-borne mosaic now causes severe losses only when a farmer fails to plant resistant varieties because he does not know about them or is willing to take a chance, or when the disease occurs unexpectedly in a new area.

HISTORY AND DISTRIBUTION

Wheat mosaic was discovered near Granite City in Madison county, Illinois, in the spring of 1919. At first it was mistakenly identified as "take-all." Closer study showed the trouble was not take-all, and the new disease was called rosette because of the abnormal appearance of diseased plants of Harvest Queen (also known locally as Salzer's Prize Taker or Red Cross), the variety in which the disease was first observed.

Through soil sterilization, it was soon demonstrated that the infective agent was soil-borne; and by 1923[7, 8] evidence had accumulated to indicate that the rosette disease was probably of a virus nature. It had been noted that on infested soil some other varieties that did not produce rosette symptoms did show mosaic-like leaf mottling. By 1925[9] it had been determined that the disease could be transmitted by juice from diseased plants, and that rosette and leaf mottling could be produced by inoculation with the same virus. Since that time the terms "wheat mosaic," "soil-borne wheat mosaic," and "Prairie wheat mosaic" have been used as common names for this disease; and "rosette" has been retained as a name for a symptom produced only by some susceptible varieties.

Infected wheat has now been found in 43 counties in Illinois. The

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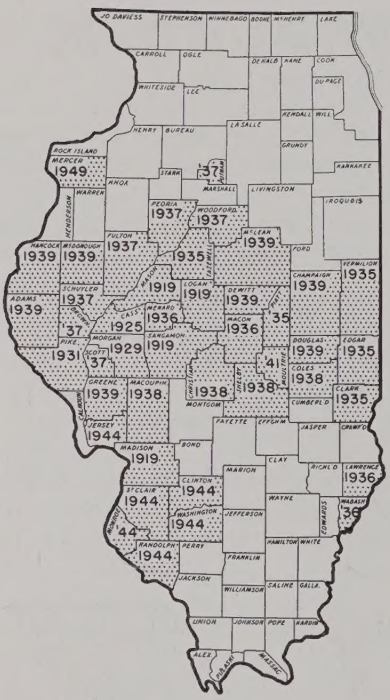


Illinois counties in which soil-borne wheat mosaic has been found and the year of its discovery. The disease was often identified after farmers reported trouble. No careful survey of the state has been made. Obviously some counties contain much more infested soil than others. (Fig. 1)

counties and the year in which the disease was first observed are shown in Fig. 1. In some counties the areas of infested soil are widespread, while in others they are more restricted. Surveys of the extent of infestation are difficult to make, because the disease can be identified only in the spring and only when the soil is cropped to susceptible varieties.

Besides being identified in Illinois in 1919 soil-borne wheat mosaic has been identified in the following states at the following times: Indiana, 1919; Virginia, before 1925[9]; North Carolina, before 1930[11]; Maryland, 1927[11]; Missouri, 1944[2]; and South Carolina, 1944.[1] It has also been reported from Japan.[4, 22]

This mosaic must not be confused with other wheat mosaics. The virus that causes the wheat streak-mosaic, a disease that occurs in the Great Plains,[13, 14, 18] is not soil-borne but apparently transmitted by insects. Wheat varieties known to be resistant to the soil-borne virus

are often susceptible to wheat streak-mosaic. A wheat mosaic that is not soil-borne but is transmitted by insects also occurs widely in Russia, but there are reasons to believe that it differs from our wheat streak-mosaic. A wheat mosaic has been reported from Egypt, but it also appears to differ from the one occurring in Illinois.[11, 20] An oat mosaic, caused by a soil-borne virus, occurs in our southeastern states, but it does not attack wheat.[16]

DESCRIPTION AND SYMPTOMS

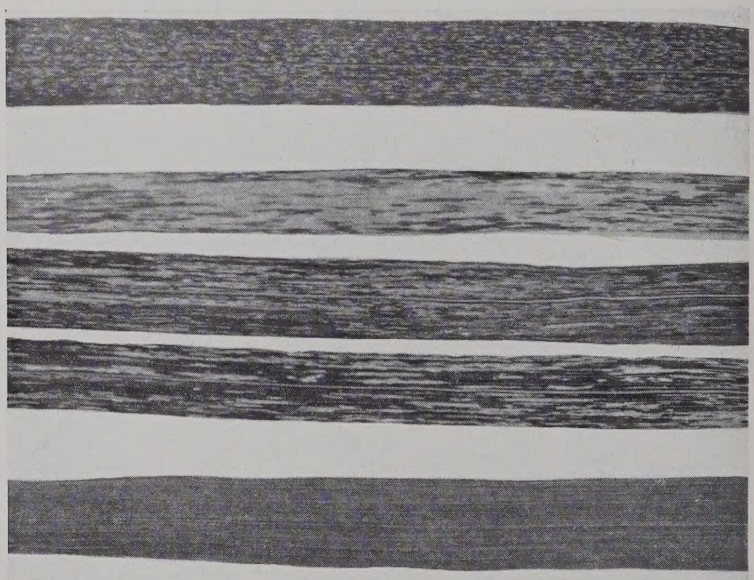
Appearance in field. Wheat mosaic, caused by soil-borne viruses, is noticeable in the spring. At that time it shows up as yellowish to light-green areas within a field, the color depending on the variety and conditions. These areas vary from less than a foot across to 50 feet or more. Sometimes nearly a whole field is involved. The wheat within the areas may be severely retarded (Fig. 2) or may be nearly normal, again depending on the variety. Some other diseases, winter-killing, water damage, and lack of proper plant food may also show up in spots or patches and be mistaken for mosaic. The best way to

Severe rosette symptoms of wheat mosaic appearing in a small area in a field of Illinois 2, a highly susceptible variety. The disease often occurs in various sized spots of this kind. (Fig. 2)

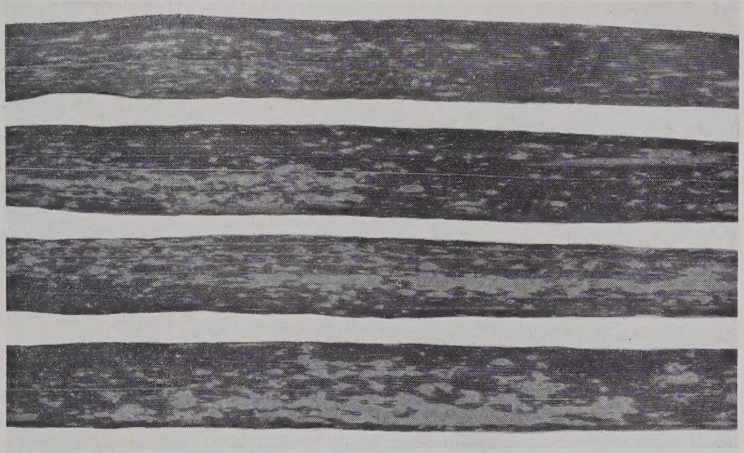
tell mosaic patches from these others is to look for the mottling of the leaves as described below.

Leaf mottling. Mottling of the leaves is characteristic of all susceptible wheat varieties infected with mosaic. It is usually most pronounced after the plants start growing vigorously in the spring and before they head out. Mottling often persists as long as the leaves are green, but usually becomes less prominent later in the growing season. It consists of irregular streaks and blotches (Fig. 3). The color of these chlorotic areas varies from an inconspicuous pale green to a pronounced pale yellow. The light-green or yellowish color may even involve the major leaf area, leaving irregular streaks of green (Fig. 3).

Distinguished from nonparasitic mottling. Some other kinds of mottling or spotting are not caused by mosaic. These nonparasitic mottlings and spotting occur in various shapes and sizes, but they do not usually follow the mosaic pattern (Figs. 3 and 4). If a con-



A healthy leaf (*bottom*); three leaves showing mosaic mottling (*center*); and one type of nonparasitic mottling (*top*). Mosaic mottling sometimes shows the striking contrasts pictured here. More often, however, the color of the mottling is less conspicuous, and sometimes the leaves must be inspected closely before the disease can be identified. (Fig. 3)



Mottled wheat leaves, apparently nonparasitic and possibly resulting from water soaking of intercellular spaces. Mottling of this type is at times very prominent on Clarkan, Chiefkan, and some other varieties. Such mottling may occur in soils that appear to be free from soil-borne mosaic virus. (Fig. 4)

siderable number of plants are available for examination, mosaic can usually be identified without trouble.

Some spotting is believed to be caused by nutritional disorders[9, 19] occurring under certain growing conditions. This spotting may be widespread in some years and relatively absent in others. It has also been reported[3] that water-soaking through open stomata may cause spotting. Under some conditions many wheat varieties show this tendency toward nonparasitic spotting. The leaves of the varieties Clarkan and Chiefkan often carry large spots. Some varieties, however, such as Brill, are nearly always free of nonparasitic mottling.

Rosette. The effect of mosaic on winter wheat, both on length of leaves and tillers, varies in the spring with the susceptibility of the variety and its characteristics. In some varieties the leaves and tillers remain short, growth is compact, and the number of tillers excessive (Fig. 5). This condition is called rosette. The leaves of such plants are sometimes a somewhat bluish green and they occasionally remain this color throughout the growing season. At other times rosetted plants die early without developing much green and may disintegrate and blow away before the time when they should have reached maturity (Fig. 6). Though mottling occurs in rosetted plants, it is not so

Here the percentage of rosetted plants is high. The original parents of the two mosaic-resistant varieties, Prairie and Royal, were healthy plants found in such a badly diseased field as this, one plant becoming the parent of Prairie, the other of Royal. At the time the two selections that produced Prairie and Royal were made, 198 other healthy plants were also selected for testing. All except Prairie and Royal were later discarded. Some proved susceptible to mosaic; some were inferior to Prairie and Royal in other respects. (Fig. 5)

clearly defined as in nonrosetting types because it is most characteristic of more actively growing leaves.

Symptoms in nonrosetting wheat varieties. In nonrosetting wheat varieties the plants may be very severely stunted and have few leaves. The elongation of the tillers is not usually completely repressed, however, and the plants do not have the rosette appearance. Some plants may be killed; on others the number of stems and heads is reduced, the heads may be shorter, maturity is delayed, and the kernels are lighter in weight than the kernels of noninfected plants. Severity may be of all degrees, depending on the resistance of the variety and the virulence of the infection.

Mosaic has greatly reduced this stand of wheat. The dead plants had largely disappeared by the time this picture was taken. Such fields often become very weedy. (Fig. 6)

Symptoms vary with severity of disease. In soils having a high virus infestation and in a season favorable to the development of the disease, all commercial varieties of wheat tested in Illinois have shown some degree of mottling. Some varieties, however, do not appear to suffer any appreciable ill effect from the disease. These varieties are classed as "resistant." With a milder expression of the disease, resistant varieties show little or no mottling, whereas susceptible varieties may still be heavily mottled and badly injured.

In relatively pure varieties that are highly susceptible to rosetting under severe conditions of the disease, 98 to 99 percent of the plants have usually rosetted. A study of head selections of the other 1 or 2 percent indicates that some escaped infection, some were mixtures or outcrosses with other varieties, and some may have been mutations (see pages 582-584). With somewhat milder infection, the percentage of rosetted plants is progressively less until few are found. But with mild infection, the percentage of mottled leaves may still be high. Thus under mild infection a rosette-susceptible variety may give the appearance of a moderately resistant, nonrosetting type. When the soil infestation is widespread in a field, however, some spots where the infection is severe enough to produce rosette in rosette-susceptible varieties can usually be found.

Symptoms develop with the season. With a long period of cool growing weather in the fall, wheats may show some mottling, but fall mottling is the exception and when it does occur usually passes unnoticed.

In the early spring the plants of susceptible varieties and even of some moderately resistant ones in infected areas are in general a yellowish color. At this stage of its development (late March at Urbana), the disease is almost impossible to identify with assurance. As the weather becomes warmer, however, the new leaves show the mottling which is the best diagnostic symptom, and rosetted plants can be distinguished from nonrosetted. By this time the color of nonrosetted infected areas has changed from greenish yellow to yellowish green, the areas becoming more and more green as the plants approach heading.

CAUSE AND CROPS AFFECTED

Soil-borne wheat mosaic is caused by a virus, *Marmor tritici* H. emend. McK.[14] There are at least two strains, or varieties, of this virus, the green-mosaic virus and the yellow-mosaic virus. These strains were so named because, when plants were artificially inoculated

with purified strains of the virus and grown under controlled conditions, the mottling characteristic of one strain was green, that of the other yellow. Only the green variety, *Marmor tritici* var. *typicum* McK., causes both rosette and mottling.

While mottling occurs in nearly all varieties of wheat, rosetting occurs only in some. In nonrosetting wheat varieties the yellow mosaic, *Marmor tritici* var. *fulvum* McK., may cause the more severe injury.[13] Green mosaic may produce rather yellow mottling on some varieties, but under the same conditions it will not be so yellow as the mottling of yellow mosaic.[11] The same difference holds under field conditions, but there it is often difficult or even impossible to distinguish one type from the other because wherever natural soil infestation occurs, both strains usually occur together.

Some varieties of wheat are susceptible primarily to green mosaic, while some others are susceptible primarily to yellow.[17] Many others are highly susceptible to both.

Soil-borne mosaic is of importance only on fall-sown wheat, barley, rye, emmer, and spelt. Varieties of common, club, poulard, durum, and Polish wheats are susceptible.[9, 11] Spring wheats sown in the spring are not damaged, but some spring wheat varieties are susceptible when sown outdoors in the fall and protected against winterkilling or when grown indoors under controlled conditions.[11]

A wild annual bromegrass, *Bromus commutatus* Schrad., has been found to be susceptible,[13] but most wild grasses appear to be immune.

This virus is not transmitted through the seed.

RELATION TO SOILS AND WEATHER

Soil topography. Soil-borne mosaic is usually most concentrated in low places or in depressions on slopes over which drainage water passes. Apparently the water concentrates the virus at these places. Webb[25] showed that when water is washed through infested soil, the water, as far as could be determined, remained free of the virus. But silt from infested soil, carried by water, contained the virus.

Sometimes, however, soil infestation seems to have little or no relation to topography, occurring on high ground as well as on low.

Temperature. To show severe disease symptoms, wheat plants must remain at a cool temperature, an average of 60° F. or less, for six weeks or more.[4, 13, 24] Freezing temperatures are not necessary for mosaic infection.

Moisture. Soil-borne mosaic is usually most prevalent in seasons when the rainfall from October through March is ample. In just which of these months moisture is most important has not been determined. Working under greenhouse conditions, Webb[24] reported that: "A high soil-moisture content decidedly favored the occurrence of both rosette and leaf mottling, whereas a medium soil-moisture content was proportionately less favorable. No indications of symptoms appeared under the low soil-moisture contents." As the weather becomes warmer, abundant moisture has the opposite effect; it aids recovery of the plants.

Seasonal variations. In some years many more occurrences of mosaic are reported than in others. On farms where test plots have been located over a period of years, the severity of the disease varied considerably from year to year. At some other locations the disease recurrence has been more regular.

Persistence of soil infestation. On black gumbo soil near Granite City in Madison county, where mosaic studies were carried on for six years, the degree of infection in the wheat plants was consistently high. Somewhat later near West Union, Clark county, studies were carried on for twelve years on brown sandy loam. For the first eleven years the degree of infection was uniformly very severe; the twelfth year the degree of infection was slightly milder.

At a number of other places the site chosen for a test plot was in a farmer's wheat field where the disease was severe. The following year a high degree of infection was obtained in some of these test plots but not in others.

Some soils more subject to infestation than others. In 1935 Ralph Allen of Delavan, Illinois, tried a new wheat on about 25 acres and lost practically the entire crop from mosaic. The infestation had probably been there a long time, but he had not previously grown varieties that were highly susceptible to mosaic. Thereafter when he seeded this field to wheat in the rotation, he sowed resistant varieties. But to test the persistence of infestation, he also drilled in strips or small squares of susceptible varieties. While the severity of the disease varied on these test plots, he would have suffered heavy losses if he had replanted this field to susceptible varieties each time.

A different situation was found on Royal Oakes' farm at Bluffs, Illinois. In 1937 Mr. Oakes had a strip of mosaic damage about 50 feet wide in a slight depression through a field of Kawvale wheat. Since that time, usually once in four years, he has been growing

mosaic-susceptible varieties in this field, either as his main crop or in test strips. Mosaic was barely noticeable in that field again, however, until 1950, when it occurred about as it had in 1937. No diseased plants could be found in this field away from this slightly depressed area.

Thus the Allen field seems much better suited to the spread and retention of the infestation than does the Oakes field. Other comparisons of this kind have been noted. The soil of both the Allen and Oakes farms is very dark, rather flat, and very fertile. On the Roy Dickerson farm at West Union, where the disease was consistently virulent, the soil was a less-fertile brown sandy loam. Nothing more definite can be said at this time about the compatibility of the virus with different soils except that the disease has not been found on the light-colored silt loams, either rolling or flat, in southern Illinois. This area in which mosaic has not been found is flanked on either side by counties along the Illinois and Wabash rivers where it has been found.

Heat and chemical soil sterilization. The virus has been eliminated from soil experimentally by heating moist soil with live steam,[5, 9] or by applying formaldehyde[8] or other disinfecting chemicals.[6] Soil sterilization has no practical farm use, but knowledge of its effect is of experimental value.

RESULTS OF TESTS

Variety Tests on Infested Soil

Observations on the susceptibility of some wheat varieties to the rosette phase of the disease were made as early as 1920 and 1922.[8, 10, 23] The present bulletin includes data on both the mottling and rosette phases of the disease on some wheat varieties in existence in the early 1920's and on many varieties that have originated since then.

Method of testing. Where the location was suitable and the owner willing to cooperate, areas of uniformly infested soil were selected for tests in farmers' fields. In most years since 1936 three such plots have been used for tests, each in a different county. The tests have been of two kinds. One consisted of two replications of 6-foot rows planted in order to obtain data on mosaic symptoms only. In this test were included winter wheats that might be suited to Illinois conditions, parent material for breeding, hybrid selections, and some varieties of rye, oats, and barley. On one occasion varieties of annual and perennial grasses were also tested.

The second kind of test had a twofold purpose: to secure data on symptoms and also on the effect of mosaic on yield. In this test 4-row

plots 18 feet long were replicated at least four times. Only the two center rows to a length of 16 feet were harvested for yield (Fig. 7). The varieties were limited for the most part to those that had shown promise in yield trials by the Illinois Station on noninfested soil.

Effect on stand and tillering. Stand was not affected until about the middle of May, when many diseased plants usually began to die. This reaction was true of rosetted plants and of weak plants of highly susceptible nonrosetting varieties such as Tenmarq. In different experiments and with different varieties, the rate of mortality varied from a few plants to 95 percent.

If rosetted plants remain alive, they usually mature only a few small heads. Badly diseased nonrosetted plants, if they live, usually produce only a few tillers. On rosetted or nonrosetted plants that are badly diseased, the heads are short and mature abnormally late. Even rosetted plants, however, may under very unusual conditions make considerable recovery.[8]

Effect on weight of seed and yield of grain. In susceptible varieties reduction in yield is due primarily to fewer seeds. But the kernel weight is also reduced (Table 1), and the lower kernel weight reduces the test weight per bushel.

On mosaic-infested soil, wheat varieties differ significantly in yield (Table 2). Some varieties apparently make a normal yield even though they may show some mosaic symptoms.[8]

On the whole, the correlation between rank in yield and the extent of mottling was good. The average percent of mottled leaves in the first 20 varieties was 26.7, while the average of the last 20 was 84.7. All varieties having a high percentage of rosette ranked at the bottom in yield.

Though the correlation between rank in yield and extent of mottling was good, rank in yield and freedom from mosaic mottling did not precisely correspond for three reasons. *First,* some wheats yield more than others in the absence of mosaic. Shepherd, for example, is highly resistant to mosaic but is inherently a low-yielding variety. *Second,* some varieties have the ability to recover to a greater extent

[8] The "comparable" yield shown in Table 2 for each variety was calculated by taking as 100 percent the average yield of those varieties that were considered resistant. The percentage yields of each variety, grown in different years and on different locations, were then averaged. This method introduces additional experimental errors, especially in that there are other hazards that affect yield, some of which are more active at one time and place than at another. An attempt was made to minimize these errors by omitting data from tests in which there was significant rust damage, as in 1937, or winterkilling, as in 1941.

A wheat variety test plot on mosaic-infested soil in central Illinois. The most resistant varieties were the most vigorous, were the darkest green, and appear darkest here. Susceptible varieties showed varying degrees of yellowing when this picture was taken on April 14, the most susceptible had many dead leaves. The data in Table 2 were obtained from such test plots. (Fig. 7)

Table. 1. — Kernel Weight of Selected Wheat Varieties Resistant or Susceptible to Soil-Borne Mosaic *(Marmor tritici)*, When Grown on Clean Soil and on Infested Soil, 1939 and 1940

Variety	Weight per 100 kernels when grown on—		Ratio of weights (clean to infested soil)
	Clean soil[a]	Infested soil[b]	
Resistant	*grams*	*grams*	
Fulcaster	2.56	2.60	
Fulhard	2.62	2.56	
Nabob	2.44	2.60	
Prairie	2.36	2.36	
Thorne	2.67	2.72	
Wabash	2.56	2.46	
Average	2.54	2.55	1:1.004
Moderately susceptible			
Brill	2.70	2.34	
Ilred	2.62	2.22	
Turkey	2.37	2.12	
Wisconsin 2	2.64	2.27	
Kawvale	2.57	2.36	
Michikof	2.42	2.27	
Average	2.55	2.26	1:0.886
Very susceptible			
Cheyenne	2.23	1.98	
Clarkan	2.78	2.52	
Illinois 2	2.19	1.83	
Iowin	2.57	1.92	
Purdue 1	2.15	1.77	
Purkof	2.62	1.98	
Tenmarq	2.73	2.20	
Average	2.47	2.03	1:0.822

[a] Average of tests in Champaign and Logan counties. [b] Average of tests in Clark, Mason, and Tazewell counties.

than others. Pawnee, for instance, may show severe symptoms in the spring but usually makes surprising recovery. The consequence is that in yield it ranks well above Blackhawk, which appears to have equally severe symptoms in the spring. *Third,* some susceptible varieties are more tolerant than others. Although they may have a high percentage of mottled leaves, they do not show the marked early-spring yellowing and their growth appears to be nearly normal. Saline is one such tolerant variety.

Data on the mosaic reactions of a considerable number of varieties, many of them not included in Table 2, are given on pages 597-599. There data are included from all tests in which a high percentage of rosette developed in the check rows planted to the susceptible varie-

Table 2. — Yield of Winter Wheat Varieties and Their Reaction to Soil-Borne Mosaic When Grown on Infested Soil, Central and South-Central Illinois, 1936-1949

(Varieties are listed in order of yield)

Variety	Kernel texture	Yield tests			Mosaic symptoms[a]	
		Years grown	Tests made	Comparable yield[b]	Mottling	Rosette
				perct.	*perct.*	*perct.*
Seneca	Soft	1	3	107.3	35	0
Butler	Soft	1	3	107.0	43	0
Illinois 36-686	Soft	1	2	106.3	0	0
Saline	Soft	1	3	105.7	67	0
Illinois 37D-214 (Duffy Sel.)	Hard	1	1	103.7	5	0
Newcaster	Soft	2	3	103.2	22	0
Nabob	Soft	4	8	102.1	12	0
Fulcaster	Soft	4	9	100.8	26	0
Duffy	Semihard	3	7	100.7	21	0
Fairfield	Soft	2	5	98.9	43	0
Wabash	Soft	5	12	97.5	34	0
Illinois 37-1153	Semihard	1	1	97.0	10	0
Michigan Amber	Soft	3	6	96.8	37	0
Clarkan Sel. 43-708	Semihard	1	2	96.4	6	0
Illinois 37-1146	Hard	1	1	96.1	10	0
Prairie	Soft	6	13	95.0	39	1
Fulhard	Hard	3	6	94.0	26	0
Quivira	Hard	1	1	93.3	39	0
Thorne	Soft	3	7	93.1	37	0
Royal	Soft	2	5	92.2	22	2
Purdue 14	Hard	1	2	90.9	50	0
Vigo	Soft	1	3	90.7	54	0
Harvest Queen USDA Sel. 34-1	Soft	3	5	90.1	15	0
Red Wave	Soft	2	3	89.9	31	0
Wisconsin 2	Hard	2	5	88.7	65	0
Ilred	Hard	3	6	88.5	38	0
Cooperatorka	Hard	2	5	86.3	17	0
Triumph	Hard	1	3	84.6	99	0
Shepherd	Soft	2	5	83.8	5	0
Pawnee	Hard	2	5	83.0	98	0
Westar	Hard	1	3	82.5	51	0
Comanche	Hard	2	5	82.4	48	0
Trumbull	Soft	2	4	80.9	37	0
Kawvale	Semihard	4	5	79.5	81	0
Fulhio	Soft	3	4	78.1	5	0
Minturki	Semihard	1	1	77.1	92	0
Turkey Red	Hard	2	4	77.0	69	1
Minter	Hard	1	2	75.5	100	0
Brill	Hard	6	12	74.2	93	0
Marmin	Hard	2	3	72.7	77	0
Blackhawk	Soft	2	5	68.7	98	0
Michikof	Hard	1	2	62.8	71	0
Iowin	Hard	2	4	55.7	98	0
Purkof	Semihard	5	9	53.5	90	0
Cheyenne	Hard	4	9	50.9	84	0
Harvest Queen	Soft	1	2	49.1	77	71
Hardy Northern	Hard	1	1	43.3	53	0
Tenmarq	Hard	5	8	41.4	97	0
Nebraska 1063	Hard	1	1	38.3	98	0
Clarkan	Semihard	3	8	36.2	93	77
Moking	Semihard	1	3	27.1	99	90
Illinois 2	Soft	5	8	24.6	98	96
Purdue 1	Soft	3	5	20.9	96	93

[a] These data are based on two kinds of tests: (1) for mosaic symptoms only; and (2) for mosaic symptoms and effect of mosaic on yield. [b] For the way comparable yield was calculated see footnote on page 578.

ties Harvest Queen or Illinois 2. Different tests, however, showed differences in the virulence of the disease. These differences were best indicated by the reactions of certain resistant varieties which varied from 0 to 100 percent in mottled leaves. The tests also included many varieties and selections that have been omitted from the summary because there apparently is no longer much interest in them. A complete report on early investigations, 1923-1931, has been made by McKinney.[12]

Most of the named high-yielding resistant soft wheats listed in Table 2 are available and recommended for south-central and southern Illinois. Prairie, Saline, and Royal are the only ones of these soft wheats that are sufficiently winter-hardy to be recommended for north-central Illinois. They are not recommended, however, for planting in a hard-wheat area unless experience indicates it to be advisable to sow them for mosaic-disease control. Several mosaic-resistant hard wheats are listed in the upper third of Table 2, but none of them are recommended for Illinois.

Breeding for Resistance

Soon after the discovery of mosaic rosette, McKinney[8] found resistant wheat could be obtained by selecting resistant plants from populations growing on infested soil. He obtained resistant selections from Harvest Queen and Illini Chief, two varieties very susceptible to the rosette phase of the mosaic disease. He also found that mosaic-resistant lines could be developed from a variety such as Nittany, which is very susceptible to mosaic mottling but is immune to rosette. Successful selection for resistance depends on the use of test plots in which severe disease symptoms are prevalent in the susceptible control each season over a period of years. A recheck for the second or third season is important, as a small percentage of the disease-free plants prove to be escapes. The selection Harvest Queen 34-1 gave a 90.1-percent yield, whereas the original variety had a yield of 49.1 percent (Table 2). This difference in yield appeared to be due entirely to mosaic resistance. But because other higher-yielding resistant soft wheats were soon introduced, these earlier selections never became commercial varieties.

In 1935 Illinois 2, a very winter-hardy variety resistant to stem rust, was discovered to be highly susceptible to mosaic. Mosaic-resistant plants were selected from a field of severely diseased wheat (Fig. 5); the final selections are the varieties Prairie and Royal. These varieties differ from each other and from the original variety in a number of characteristics, but they are also like the parent type in

many respects. Prairie may be only a variation in the parent type. But since Royal has white chaff and Illinois 2 brown chaff, it is likely that Royal is the result of a natural cross. Resistant selections have also been made from Clarkan, Duffy, and other varieties, and resistance obtained, but these selections fell short in some other important respects.

An advanced generation of a cross between Illinois 2 and Gladden, tested for the first time on mosaic-infested soil. Note segregation for resistance and susceptibility: one plant (*right*) is healthy; two show rosette (*center*); and two others (*left*) show mottling and stunting but no rosette. (Fig. 8)

A more recent mosaic-resistant release from the Illinois Station, Saline, was a selection from Illinois 2 × Gladden. A number of individual plants from an advanced generation of this cross are shown in Fig. 8. The segregations show all variations from one highly resistant plant to others extremely susceptible.

A number of good-yielding mosaic-resistant hard wheats have been produced (Table 2), but they have had faults that have made them undesirable. Illinois 37D-214 has weak straw and is susceptible to rust; Illinois 37-1146 is susceptible to loose smut; Fulhard (Kan.) has weak straw and is susceptible to rust; and Quivira (Kan.) lacks winter-hardiness and produces off-colored flour. There does not seem to be any reason, however, why a good mosaic-resistant hard wheat could not be developed.

The major wheat-breeding effort at Illinois, however, is being

directed toward the development of better soft wheats. The climate of Illinois is such as to favor the production of a high-quality soft wheat rather than a high-quality hard wheat.

The only mosaic-immune wheat variety[a] in Table 2 is Illinois 36-686, a selection from a cross (Gladden×Illinois 2, F_1)×Gladden. It is one of a number of selections immune to mosaic under field conditions that have come from the breeding plots.[b] This one has proved useful in some of the mosaic-disease experiments as a disease-free check, but it will not be released for general use because of its susceptibility to loose smut. These immune selections have been produced from crosses, neither of the parents of which were immune. This effect is known as transgressive segregation.

Crop Rotation

Infestation with the wheat-mosaic virus seems to occur only in cultivated soils. Tests for the virus were made in a permanent pasture, an old orchard, and several road sides — all within several hundred feet or less of severely infested cultivated soil. In each case the site had been in sod of long standing, primarily bluegrass, and there had been no water drainage or washing from the infested area to these test sites. The sod was turned in midsummer, worked down and planted to susceptible wheat in the fall, and covered with a wire-mesh hurdle to protect the plants against damage. The test plants showed no trace of mosaic symptoms.

An experiment was conducted on the Roy Dickerson farm in Clark county to determine the persistence of soil infestation when various crops are planted continuously for four years. An area that had been cropped experimentally to wheat for a number of years and had shown severe mosaic each year was selected. Twelve squares 8 feet by 8 feet were enclosed with creosoted 2-by-10-inch planks sunk into the soil, with about 4 inches protruding above ground. The plots were planted in duplicate and cropped six different ways continuously for four consecutive years (Table 3). In the fifth year all plots were sown to wheat. Two susceptible varieties, Illinois 2 and Marmin, and an immune variety, Illinois 36-386, were planted in duplicate on each plot, making a total of four replications. Results were measured by the percentage yield of the susceptible wheats compared with the yield of the immune wheat.

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[a] Immunity to disease means the complete absence of the disease, whereas resistance means comparatively little damage from it.

[b] It has been shown by McKinney[17] that wheats immune from soil-borne mosaic viruses in the field may be susceptible when inoculated manually.

Table 3. — Severity of Wheat Mosaic as Related to Previous Cropping: Two Susceptible Varieties Compared With One Immune Variety

(Roy Dickerson farm, West Union, Illinois, 1946)

Crop grown each year during first four years	Mosaic reaction in fifth year: plots cropped uniformly to susceptible and immune wheat		
	Rosetted plants in Illinois 2	Yields of mosaic-susceptible varieties[a]	
		Illinois 2	Marmin
	perct.	*perct.*	*perct.*
Illinois 2 wheat (susceptible to mosaic)	80	15.3	35.8
Illinois 36-686 wheat (immune to mosaic)	9	40.7	64.8
Clinton oats	0	48.3	67.1
Illini soybeans	5	40.3	77.7
Hybrid U.S. 13 corn	4	41.7	74.6
Kansas common alfalfa	28	28.0	63.9
Difference needed for significance (5-percent level)	..	20.3	14.3

[a] Yield of the immune variety, Illinois 36-686, is taken as 100 percent.

Unfortunately the final results were obtained in a year (1946) when the mosaic damage in that area was less than in previous years. In the square cropped continuously to Illinois 2, the percent of rosetted plants had been about 95 to 98 year after year. In the final test year the average was only 80 percent. Nevertheless, previous cropping did make considerable difference in the expression of the disease, as indicated by rosetted plants and reduced yield (Table 3). In all plots Illinois 2 yielded less than half as much as the immune wheat. The alfalfa was broadcast and therefore could not be clean-cultivated, as were the other crops. Various weeds, including wild grasses, became established, and thus there may possibly have been a wild host.

This experiment indicates that cropping with nonsusceptible crops tends to reduce the damage from mosaic, but crop rotation cannot be recommended as an adequate control measure. This experiment also tends to explain why the disease has been most active in those areas of the state where wheat is grown most extensively. It also suggests that a test field for determining resistance to mosaic should be planted to a susceptible wheat variety frequently, preferably annually, to maintain a high level of infestation.

Depth Virus Penetrated the Soil

Tests for virus infestation were made of subsoil from two locations, one in Clark county, the other in Cass. In both places the surface soil was known to be severely infested. In Clark county the surface soil was a brown sandy loam and the subsoil a porous gravelly clay loam. In Cass county the surface soil was a dark sandy loam and the subsoil to the depth examined had much the same appearance.

At the site of the tests a garbage can of soil was taken from each of four levels: the surface to a depth of 4 inches, and strata 8 to 10, 16 to 18, and 24 to 26 inches deep. All samples were brought to the Station farm at Urbana, where small plots were established on a non-infested soil that had been covered by an old bluegrass sod. Frames 18 by 24 inches on the inside were made from 1-by-6-inch boards. Rectangles of sod to accommodate these frames were removed to a depth of 3 inches, and the frames inserted and filled to a depth of 3 inches with the soil to be tested. (Fig. 9 shows similar frames.) Mixed fertilizers were added. Two varieties of susceptible wheat were used as indicators of infection.

Plants grown in the Clark county soil showed an equally high degree of infection regardless of the soil strata in which they were grown. Those grown in the Cass county soil taken at the 16-18-inch level showed infection, but no infection was found in those grown in the soil taken from the 24-26-inch level. The tests further showed that the disease was as severe in the test plots where the infested soil was only 3 inches deep as it was in the field from which the soil came. From this it can be concluded that deep virus penetration does not affect the severity of the disease. How much infested soil there must be around the seed before the disease can reach maximum severity was not determined.

Dried Soil Remained Infectious

McKinney[13] reported in 1937 that heavily infested gumbo soil from Granite City, Illinois, that had been kept dry in the laboratory for three years was still infectious and induced mosaic rosette in a high percentage of the wheat plants grown in it. More recently, infested dark sandy loam from near Beardstown, Cass county, Illinois, was stored dry at Urbana for four years with similar results.

In another experiment infested soils from both Clark and Cass counties were each put through a 4-mesh screen and placed not more than 1 inch deep in large metal pans for 10 days in May. The pans were kept in an empty greenhouse where it was hot and dry, day

temperatures usually going above 100° F. The soil was stirred daily and became extremely dry. When it was tested for mosaic, it was found to be just as infectious as similar soil not so treated.

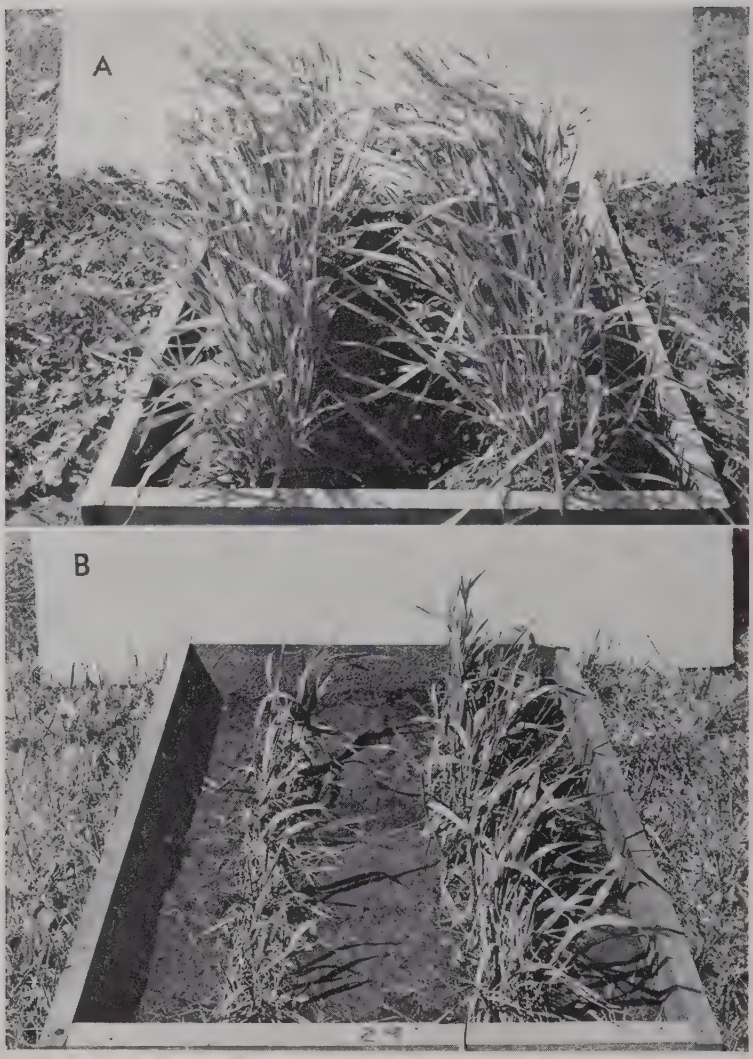
These experiments indicate that the virus might be spread by wind-borne infested soil. It will be shown below, however, that it requires a number of years of cropping with susceptible wheat for infestations to build up to a damaging degree from the additions of small amounts of infested soil to clean soil. In areas where little wheat is grown, the virus may have no chance to increase and cause mosaic. Furthermore, in some soils the virus may possibly never build up at all, for some soils appear not to retain infestation as well as others. (For discussion of this point see pages 576-577.) It is also possible that the virus may not be in the soil in a free state, and that it may be associated with some organism that serves as a vector.

Build Up of Infestation in Clean Soil

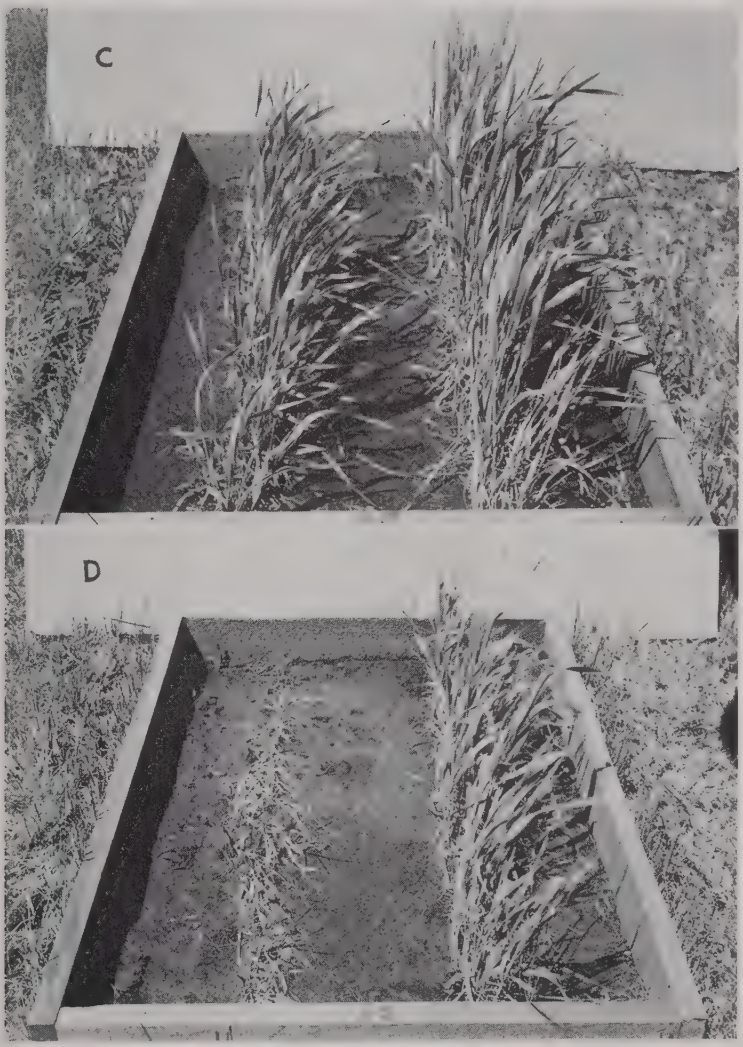
Build up of wheat mosaic virus in clean soil was investigated in an area of fertile dark silt loam on the Station farm at Urbana. This soil was covered by an old bluegrass sod and was known not to be infested. Wooden frames 18 by 24 by 6 inches deep were installed as previously described (see page 586) and filled with 3 inches of the soil to be tested. Each year they were planted to a row of Illinois 2 and Blackhawk wheat.

Three noninfested soils were used: (1) soil from the location where the test was to be made; (2) Clark county infested soil, steam-sterilized; and (3) noninfested Clark county soil from a location in an old pasture not over 100 feet from severely infested soil. The following plots were established for each soil: (1) check plot, no infested soil added; (2) 0.01 percent of infested soil added; (3) 0.1 percent of infested soil added; (4) 1 percent of infested soil added; and (5) 10 percent of infested soil added. The infested soil came from Clark county and the test also included a plot of undiluted infested soil. The additions were made by weight, and the soil was thoroughly mixed before being placed in the frames.

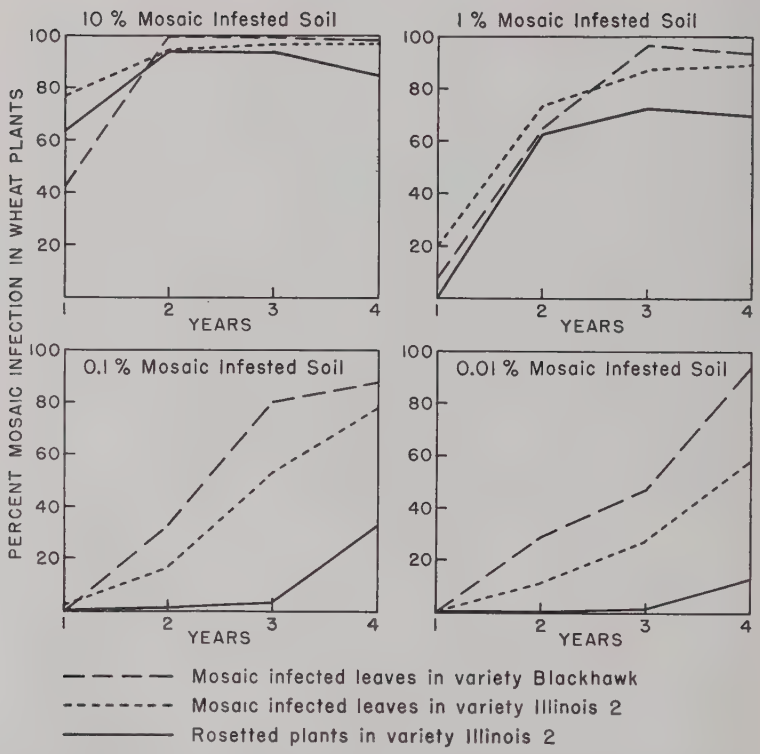
During the four-year test the build up of infestation in the two Clark county soils was about the same and a little faster than in the Urbana soil. The average for all three soils is shown graphically in Fig. 10. The photographs A and B in Fig. 9 show the same plot in the first and fourth year of the test. This is one of the plots to which 1 percent of infested soil had been added at the beginning of the tests. In the first year there was a little mottling but no rosetting and no apparent



Two views of the same test plot are shown above (**A**, 1946; **B**, 1949). These plots and the two shown on the opposite page (**C** and **D**, 1949) were planted to two susceptible wheats, Illinois 2 (*left row*) and Blackhawk (*right row*). All were photographed in late April. When 1 percent of soil infested with mosaic virus was mixed with noninfested soil, mosaic damage was slight the first year (**A**), but had increased greatly by the fourth year (**B**). Damage



was still not as great here, however, as on the undiluted infested soil of **D**, where in each of the four years 98 to 99 percent of the plants of Illinois 2 rosetted and all leaves of Blackhawk showed mottling. Where only 0.01 percent of mosaic-infested soil was added (**C**), no mosaic symptoms appeared the first year; by the fourth year, shown here, damage had occurred but was comparatively mild. (Fig. 9)


10 % Mosaic Infested Soil
1 % Mosaic Infested Soil
0.1 % Mosaic Infested Soil
0.01 % Mosaic Infested Soil
PERCENT MOSAIC INFECTION IN WHEAT PLANTS
YEARS
Mosaic infected leaves in variety Blackhawk
Mosaic infected leaves in variety Illinois 2
Rosetted plants in variety Illinois 2

Annual increase in mosaic-infected leaves showing mottling and in rosetted plants after 10, 1, 0.1, and 0.01 percent of soil infested with mosaic had been mixed with noninfested soil. (Fig. 10)

loss in vigor. In the third and fourth years mosaic, including rosetting, was severe although still not as severe as on undiluted infested soil (Fig. 9D). In the plots started with only 0.01 percent of infested soil, mosaic infection after four years was only mild (Figs. 9C and 10). The two lower graphs in Fig. 10 also show how rosetting progresses more slowly than mottling in lightly infested soil. The plots started with noninfested soil remained free from mosaic throughout the test.

Previous two-year tests by Webb[25] with low percentages of infested soil and a more limited range of dilutions had also indicated that mosaic-virus infestation tends to build up by repeated cropping to susceptible wheat.

Effect of Soil Fertility

Soil-borne wheat mosaic apparently cannot be modified enough by soil fertilizers to benefit farmers. Good fertility improves the yields of both susceptible and resistant wheats on infested soil, but the difference that mosaic causes still persists. McKinney[8, 15] applied limestone and commercial fertilizers, rock phosphate, acid phosphate, stable manure, potassium sulfate, and sodium nitrate to experimental plots on infested soil. The differences the fertilizers caused in mosaic symptoms were slight. High nitrogen levels tend to obscure the symptoms of the disease and cause infected susceptible plants to look healthier. Nitrogen levels high enough to produce this appearance, however, cause resistant or noninfected wheat plants now commonly grown to lodge before they mature.

From 1941 to 1945 conditions of soil fertility were studied in twenty mosaic-infested fields in thirteen counties. Fields were selected in which there were areas where mosaic was severe and nearby were areas mosaic-free or nearly free. For comparison, soil samples were taken from both areas. The samples were tested for total available phosphorus, adsorbed phosphorus, replaceable potassium content, and lime requirement.[a] In both areas the mineral content and lime requirement varied greatly, the mineral content ranging from low to high and the lime requirement from 0 to 5 tons an acre. In each field, however, the infested areas usually had the higher content of both available and adsorbed phosphorus and sometimes had a higher potassium content. Such relationship, however, may have been coincidental, for the infested areas had a tendency to be lower than the noninfested areas. The differences in the lime requirement were not consistent.

In September, 1941, on the Ralph Allen farm in Tazewell county, fertilizer test plots were established on soil having a moderate mosaic-virus infestation. The plots consisted of strips 8 feet wide. Duplicate plots were treated as follows: (1) check; (2) horse manure, 12 tons an acre; (3) cow manure, 12 tons an acre; (4) pig manure, 10 tons an acre; (5) commercial fertilizer 0-20-0,[b] 300 pounds an acre; (6) commercial fertilizer 0-20-20, 300 pounds an acre; (7) commercial fertilizer 0-20-20, 300 pounds an acre, plus 150 pounds of ammonium sulfate an acre applied at planting time and an additional 150 pounds in the spring. In the plots that received horse manure, cow manure,

[a] Soil tests for available nutrients were made by R. H. Bray and S. W. Melsted, soil fertility division, Department of Agronomy.

[b] Commercial fertilizer 0-20-0 contains no nitrogen, 20 percent phosphoric acid, and no potash.

and commercial fertilizer 0-20-0, mosaic symptoms were slightly more severe than they were in the check plots; but in the other plots mosaic did not increase or the increases were not consistent.

RESISTANT VARIETIES FOR CONTROL

While frequency of cropping with susceptible wheat varieties appears to have an influence on the severity of mosaic, yet in a season very favorable to the development of the disease, serious losses may occur where wheat is grown only once in a four-year rotation. Dependence must therefore be placed on resistant varieties to combat this disease.

Although none of the commercial wheat varieties now grown are immune to mosaic, there are some highly resistant varieties in which the effects of the disease are negligible. A number of soft wheats show good resistance; others are extremely susceptible. Among the hard wheats there are as yet no highly resistant varieties that can be recommended for Illinois. Some otherwise good hard wheats, however, are injured by mosaic only moderately.

The following varietal recommendations are valid at this writing. They are based on tests made on several experimental fields representing different regions of the state.[21] Still better varieties will, however, doubtless become available as this Station and other Stations continue their breeding and testing programs.

Southern Illinois. The varieties recommended for this area are all soft red winter types having good resistance to mosaic. They are Royal, Vigo, Saline, Seneca, and Newcaster. Some of these are better adapted to certain conditions than others, but on many locations they will yield about the same.

Royal, a bearded variety, has the highest test weight per bushel in this group and a medium-stiff straw but the straw is not so stiff as that of Saline and Seneca. It is resistant to most of the common races of stem rust that occur in Illinois but is susceptible to leaf rust and loose smut.

Vigo is a smooth-headed wheat. It has medium-stiff straw, is resistant to certain races of leaf rust and loose smut but is susceptible to stem rust.

Saline is a bearded, stiff-strawed variety, slightly taller than the other varieties mentioned here. Its test weight, milling, and baking qualities are above average. It is susceptible to certain races of leaf rust and to stem rust and loose smut.

Seneca is a smooth-headed, stiff-strawed variety that bears considerable resemblance to Thorne but yields higher. It is intermediate in resistance to loose smut but susceptible to leaf rust and stem rust. It has the lowest test weight per bushel in this group.

Newcaster is bearded and considerably resembles Fulcaster from which it was selected. Of this group, it has the weakest straw, but it is well adapted to soils of medium to low fertility where it often gives the highest yield. Its resistance to stem rust and loose smut is intermediate; it is susceptible to leaf rust.

Central Illinois. Both hard and soft wheats are grown in this area, but the northern half of central Illinois is essentially in the hard red winter-wheat belt. Though they have only a moderate degree of resistance to mosaic, Pawnee and Westar are the hard wheats recommended for central Illinois. Where losses from mosaic can be expected, one of the more winter-hardy soft wheats — Royal, Prairie, or Saline — is recommended.

Pawnee is a bearded, stiff-strawed wheat. It is resistant to most races of stem rust, is highly resistant to loose and covered smuts, and is intermediate in degree of resistance to leaf rust. On infested soil it will show considerable damage from mosaic in the spring but has the ability to make a remarkable recovery. Recovery, however, will not be complete; and under the same conditions Royal, Saline, or Prairie can be expected to outyield it by 5 bushels or more an acre.

Westar is a bearded wheat, not quite so good as Pawnee in ability to stand erect. It is resistant to certain races of leaf rust and loose smut but is susceptible to stem rust. In resistance to mosaic it ranks better than Pawnee but not so high as Royal, Prairie, or Saline.

Prairie is a bearded, brown-chaffed wheat that in ability to stand erect ranks somewhat better than Royal. Except on highly fertile soils, however, it yields somewhat less than Royal or Saline.

Saline and **Royal** have yielded very well in this area. (For descriptions see page 592.)

Northern Illinois. Soil-borne wheat mosaic does not occur in northern Illinois and therefore need not be taken into consideration there. Winter-hardiness, however, is important.

Blackhawk and **Minter** are two of the best wheats for northern Illinois. Since they are susceptible to mosaic when grown on infested soil farther south, they should be grown only in the northern part of the state.

Saline and **Wisconsin 2** have yielded well and are winter-hardy enough to be recommended for northern Illinois.

SUMMARY

Distribution of wheat mosaic. Soil-borne wheat mosaic has been known to occur in seven states, all east of the Great Plains. In Illinois it has been observed in 43 central and south-central counties. Illinois appears to have a larger area of infested soil than any other state.

Symptoms. Soil-borne wheat mosaic is caused by a virus. The disease is most noticeable in the spring when it shows up as yellowish to light-green areas in fields. Leaf mottling (irregular streaks and blotches on the leaves) is characteristic of all susceptible, mosaic-infected wheat varieties.

In some varieties mosaic produces a condition known as rosette; when rosetting occurs, the leaves and tillers of the plant remain short, there is a large number of dwarfed tillers, and growth is compact. In varieties in which mosaic does not produce rosette, the plants that live may be severely stunted, the number of stems and heads may be reduced, the heads shorter, maturity delayed, and the kernels lighter in weight than the kernels of healthy plants. The symptoms vary with the severity of the disease and the variety.

Cause. At least two strains of virus cause wheat mosaic; they are *Marmor tritici* var. *typicum* McK. and *Marmor tritici* var. *fulvum* McK. Wherever natural soil infestation occurs, both strains usually occur together.

Crops affected. Soil-borne wheat mosaic is of importance only on winter wheat, barley, rye, emmer, and spelt. Spring wheats sown in the spring are not damaged. Some spring-wheat varieties, however, are susceptible when they are sown outdoors in the fall and protected against winterkilling, or when they are grown indoors under controlled conditions.

Relation to soils and weather. Where mosaic occurs in a field, it is usually most conspicuous in the lower parts of the field, apparently because drainage water concentrates the virus at these spots. Some soils seem to be much better adapted to the spread and retention of the disease than others.

To show severe disease symptoms, wheat plants must remain at a cool temperature for six weeks or more, but the temperature need not be freezing. Soil-borne wheat mosaic is usually most prevalent in seasons in which rainfall from October through March is ample. Many more occurrences of wheat mosaic are reported in some years than in others.

Development of resistant wheat varieties. When very susceptible varieties of wheat were grown on infested soil, damage was extremely severe both in farmers' fields and in experimental test plots. Early in the studies of wheat mosaic, however, evidence of good resistance in some varieties was observed. Since 1935 the wheat breeding program at the Illinois Station has been directed toward

producing superior varieties which possess, among other characteristics, resistance to wheat mosaic.

For the southern half of the state a number of soft-wheat varieties that are resistant to mosaic and are otherwise desirable have been developed and offer satisfactory protection against this disease.

For north-central Illinois, where hard wheats are usually grown, no hard wheats with good mosaic resistance can be recommended. Although some resistant varieties have been found, they possess other characteristics that make them undesirable. Hard wheats that can be recommended are therefore limited to a few varieties that possess a moderate degree of resistance to mosaic.

In northern Illinois wheat mosaic does not occur, and therefore resistance to this disease need not be considered in choosing varieties for growing there.

Other findings from tests. Keeping already infested soil in susceptible crops tended to keep the soil highly infested. Crop rotation, however, did not in itself prove an adequate control measure.

At one location natural soil infestation was found at a depth of 2 feet and may have gone still deeper. In experimental tests, disease damage was just as severe on plots infested to a depth of 3 inches as on those where the infestation was deeper.

That the mosaic virus can be carried by wind-borne dust was indicated by an experiment in which infested soil was thoroughly air-dried in the sun for 10 days under a glass roof where the maximum daily temperatures were over 100° F. When remoistened this soil was just as infective as similar soil kept moist and comparatively cool.

Infestation was built up in clean soil by adding various amounts of infested soil to the clean soil and then cropping the ground under normal field conditions to susceptible varieties of wheat for four years. Adding as little as one part of infested soil to 10,000 parts of clean soil produced considerable disease the fourth year, although the amount was still much less than that produced in wheat grown on undiluted infested soil. On the plots where higher amounts of infested soil were initially added, the evidence of severe disease appeared earlier in the four-year period.

Differences in soil fertility influence wheat mosaic very little. In some tests, adding manure or fertilizer appeared to increase slightly the percentage of leaves that showed symptoms of infection. Heavy applications of nitrogen tended to make leaf-mottling less conspicuous and to make the plants look healthier, but such applications also caused mature plants of resistant varieties to lodge.

Thus the best solution to the problem of controlling wheat mosaic lies in the development of resistant varieties that also possess all the other characteristics necessary for satisfactory yields of high-quality grain.

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APPENDIX

Table 4. — Mosaic-Mottled Leaves and Rosetted Plants in Winter Wheat Varieties Grown on Infested Soil, Central and South-Central Illinois, 1923-1949[a]

Variety	Source or C.I.[b] number	Tests made	Mosaic symptoms	
			Mottling	Rosette
Soft wheats				
			perct.	*perct.*
Albit	8275	3	0-T[c]	0
American Banner	3342	1	10	0
American Bronze (Prosperity)[d]	5638	1	85	0
Arlando	10069	4	0-10[e]	0
Ashland	Several	4	0-5	0
Bald Rock	11538	1	T	0
Berkeley Rock	6941	1	0	0
Blackhawk	12218	8	90-100	0
Butler	12527	4	10-70	0
Clarkan[f]	8858	13	70-100	20-99
Currell	Several	4	T-100[g]	0
Dietz (Fulcaster)	1981	1	T	0
Dixie (Java)	10070	1	86	0
Duffy (Fulcaster)[f]	Illinois	7	5-60	0
Early Harvest (Red May)	4852	1	T	0
Early Ripe (Red May)	5319	1	35	0
Enterprise (Red May)	3399	1	T	0
Fairfield	12013	6	T-90	0-T
Forward	6691	3	0-5	0
Fulcaster	Several	17	0-100	0
Fulhio	6999	8	0-20	0
Fultz	Several	8	T-60	0-1
Gipsy	5646	2	0-10	0-9
Gladden	Several	6	0-23	0-13
Gleason (Greeson)	6978	2	25	0-7
Goens	6992	4	0-7	0
Golden Drop (Preston)	6316	3	98-100	0
Grandprize	4896	1	95	0
Harvest King (Poole)	5647	1	4	T
Harvest Queen	Several	9	50-100	40-100

(*Table is continued on next page*)

Table 4. — Continued

Variety	Source or C.I.[b] number	Tests made	Mosaic symptoms	
			Mottling	Rosette
Soft wheats, concluded				
			perct.	*perct.*
Illinois 2	11537	19	90-100	80-100
Indiana Swamp (Valley)	Several	3	98-100	85-98
Jersey Fultz (Fultz)	Several	3	T-15	0-12
Jones Fife	Several	2	0-T	0-T
Kan Queen[f]	12762	1	98	93
Kawvale[f]	8180	8	40-100	0
Lancaster (Fulcaster)	Several	2	35	0
Mammoth Red	Several	5	0-20	0-10
Mealy	Several	3	T	0-T
Michigan Amber	Several	11	T-100	0
Michigan Wonder (Red May)	Several	2	35	0
Minhardi	5149	1	98	0
Missouri Bluestem	1912	1	60	50
Missouri Early Premium	11858	3	98-100	0
Moking[f]	12556	3	97-100	80-95
Nabob	8869	10	0-50	0
Newcaster (Fulcaster)	12472	3	0-55	0
Niagara (Valley)	5307	2	10	0
Nigger	Several	2	99	0-99
Nittany	6882	3	50-100	0
Oakley	6301	3	5-90	0
Orange (Red May)	4868	1	T	0
Penquite	3068	4	T-95	0-50
Poole	Several	2	0-97	0
Portage	5370	2	T-9	0
Posey's Blue Stem (Fultz)	Several	2	100	0
Prairie	12069	17	0-100	0-6
Pride of Indiana (Red May)	3492	1	T	0
Purdue 1	11380	3	85-100	85-100
Purple Straw	Several	2	98-100	0
Red Cross (Red May)	Several	2	T-35	0
Redhart	8898	1	70	0
Red May	Several	4	T-100	0
Red Rock	5597	2	T-25	0
Red Wave	3500	4	5-100	0
Red Wonder (Fulcaster)	5373	1	0	0
Rice	5734	3	100	0
Royal	12558	7	0-78	0-8
Rudy	Several	2	T-12	0-2
Saline	12674	5	10-93	0-3
Seneca	12529	4	13-63	0
Shepherd	6163	7	0-20	0
Sol	6009	3	100	0
Thorne	11856	6	0-100	0
Triumph	12132	5	98-100	0
Trumbull	5657	10	0-80	0
Valley	5658	1	0	0
Valprize	11539	1	T	0
Vigo	12220	6	0-88	0-T
Wabash	11384	11	T-100	0
Hard wheats				
Alton	1438	2	T-90	0
Blackhull	6251	2	5-75	0
Blue Jacket	12502	1	97	0
Brill	11853	14	50-100	0
Cache	11599	2	80-100	0
Cheyenne	8885	8	68-100	0
Comanche	11673	5	20-85	0
Cooperatorka	8861	9	0-75	0
Chiefkan	11754	2	75-95	5-10

(*Table is concluded on next page*)

Table 4. — Concluded

Variety	Source or C.I.[b] number	Tests made	Mosaic symptoms	
			Mottling	Rosette
Hard wheats, concluded				
			perct.	*perct.*
Crimean (Turkey)	5569	1	97	0
Eagle Chief	8868	2	10-98	0
Early Blackhull	8856	4	5-98	0
Early Kanred	Kansas	4	20-100	0
Fulhard	8257	10	0-100	0
Hardy Northern	Illinois	2	30-75	0
Ilred	8219	9	T-100	0
Iobred	6934	2	98-100	0
Iohardi	12510	1	100	0
Ioturk	11388	2	90-100	0
Iowin	10017	5	95-100	0
Kanred	5146	2	5-95	0
Kharkof (Turkey)	Several	4	5-100	0
Kiowa	12133	1	100	0
Lincalel	Kansas	6	0-5	0
Malakof (Turkey)	Several	2	7-95	0-10
Marmin	11502	5	10-100	0
Menno	Kansas	3	95-100	0
Michikof	6990	10	40-100	0
Minard	6690	2	100	0-10
Minter	12138	4	98-100	0
Minturki	6155	2	85-98	0
Neb. 60	6250	1	100	0
Neb. 1063	Nebraska	2	95-100	0
Nebred	10094	1	98	0
Oro	8220	4	0-100	0
Pawnee	11669	7	90-100	0
Purkof	8381	11	80-100	0
Quivira	8886	6	0-100	0
Red Chief	12109	3	98-99	50-99
Stafford	12706	1	65	0
Tenmarq	6936	10	90-100	0
Turkey Red (Turkey)	Several	9	5-100	0-8
Ukrainka	8859	3	98-100	0
Westar	12110	6	23-92	0-2
Wichita	11952	5	95-99	0
Wisconsin 2	6683	10	10-100	0-1
Yogo	8033	1	97	0

[a] The data summarized in this table include those obtained by H. H. McKinney in cooperative tests conducted at Granite City, Illinois, crop seasons 1923, 1925, 1930, and 1931.[12]* [b] C.I. = cereal investigation number, U.S. Department of Agriculture. [c] T = trace, less than 1 percent. [d] Names in parentheses are synonyms or the names of very closely related varieties. [e] Variations in percentages of a pure variety are caused primarily by variations in virulence of soil infestation and in environmental conditions. [f] These varieties are not true soft wheats but range from soft to semihard according to environment during the maturation period. [g] In seed of the same variety obtained from several sources, the variation in reaction is often caused by variations in the variety as well as in the virulence of infestation and in environment.

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